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Impregnation of Concrete Pipe for Corrosion Resistance and Strength Improvement

Southwest Research Inst.
San Antonio, TX

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

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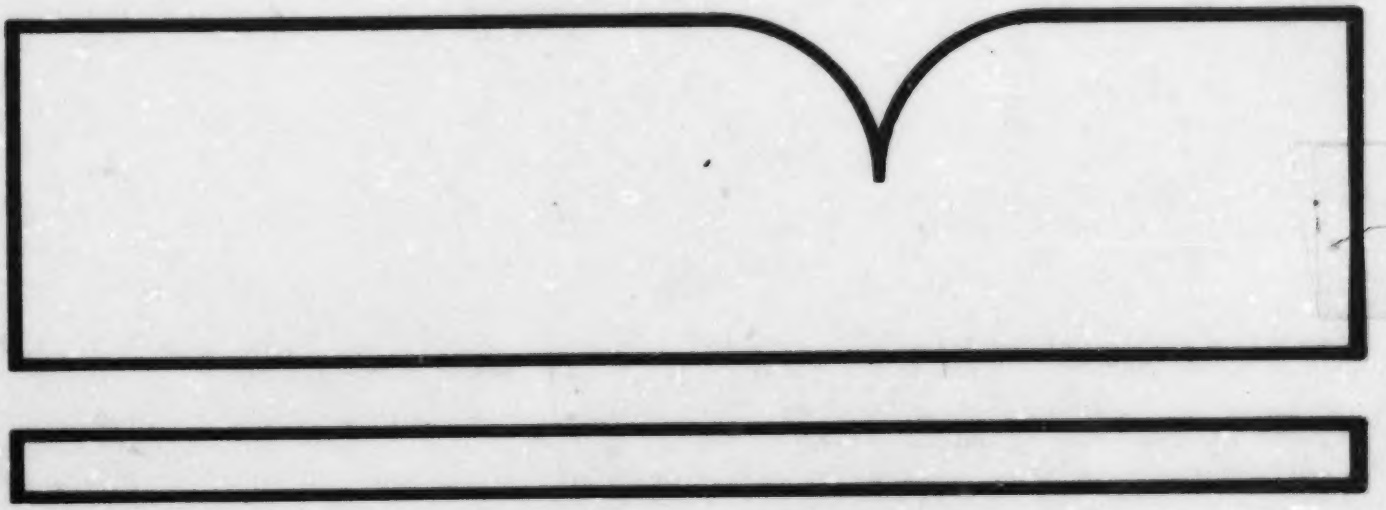

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16. ABSTRACT

This program was undertaken to field test concrete sewer pipe that had been impregnated with sulfur or hydrofluoric acid. This program was a follow-on to a previous laboratory study sponsored by EPA entitled, Impregnation of Concrete Pipe, 11024EQE 06/71. In a subsequent grant extension to the program, strength improvements using the sulfur formulations were investigated with a view to reducing costs by elimination of the steel reinforcing in certain sizes of concrete pipe.

In 1975, nearly 1400 feet (427 m) of impregnated sewer lines were installed in four Texas cities, including Dallas, Beaumont, Pecos, and Harlingen. These lines have been monitored since that time and the results of this monitoring, as well as a discussion of the strength improvement due to sulfur impregnation, are reported.

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IMPREGNATION OF CONCRETE PIPE FOR CORROSION RESISTANCE AND STRENGTH IMPROVEMENT

by

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Grant No. S802651

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the research and the user community.

Under this program field evaluations of sulfur impregnated and hydrofluoric acid treated concrete sewer pipe were made. In addition, the strength improvements due to sulfur impregnation were investigated with a view towards reducing pipe costs.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This program was undertaken to field test impregnated concrete sewer pipe as a follow-on to a previous laboratory study sponsored by the U.S. Environmental Protection Agency at Southwest Research Institute. The laboratory tests indicated that impregnation of concrete pipe improved both strength and corrosion resistance at an economically attractive cost.

Impregnation vats were fabricated for treating concrete pipe with either molten modified sulfur formulations, or dilute hydrofluoric acid solutions. Approximately 1400 ft (427 m) of concrete pipe were impregnated and installed in four Texas cities.

The City of Dallas installed approximately 1000 ft (305 m) of 10 in. (25.4 cm) and 12 in. (30.5 cm) diameter pipe at two separate locations. One, an industrial line, serves a battery plant, while the second line serves a residential area, including an orphans' home with its own water well which is high in sulfate salts. Beaumont installed 200 ft (61.0 m) of 10 in. (25.4 cm) diameter pipe in a domestic line, and Harlingen installed 100 ft (30.5 m) of 12 in. (30.5 cm) diameter pipe in a domestic line. Pecos installed 100 ft (30.5 m) of 6 in. (15.2 cm) diameter line where principal concern was with the external corrosion caused to concrete because of the high sulfate content in the soil and groundwater.

The four principal types of pipe installed in each city included untreated concrete as a control, concrete impregnated with modified sulfur (i.e. with 2% by weight of dicycopentadiene as a prohibitor against bacteria attack on elemental sulfur), concrete impregnated with modified sulfur with bactericide (i.e. 0.5% by weight of sodium pentachlorophenate), and concrete impregnated with dilute hydrofluoric acid. Other types of pipe also installed in certain locations included ductile iron, plastic, and clay. Special epoxy lined concrete manholes, fiberglass manholes, plastic manhole rings and shrink-fit joint material were also included at most of the sites.

Internal diameter measurements were taken for each type of pipe and samples of the effluent were also collected and analyzed. The monitoring was conducted in an attempt to determine measurable differences between the concrete controls and the impregnated concrete pipe. After a three year in situ evaluation program, a trend appeared to develop which indicated less corrosion in the impregnated sections than the untreated controls. However, it is felt that the sites should continue to be monitored until more pronounced results or some failure occurs.

In the strength evaluation portion of the study, it was found that sulfur impregnated nonreinforced concrete pipe approaches the ultimate strength of reinforced concrete pipe. This dramatic strength improvement, coupled with increased corrosion resistance, provided by sulfur impregnation leads to the possibility that impregnation of concrete pipe could provide more than adequate strength at lower pipe costs. For example, considerable material savings can be realized by eliminating the reinforcing steel in concrete pipe and substituting it by sulfur impregnation. These savings can vary from $0.14 to $0.27 per linear foot (.3 m) of 12 in. (30.5 cm) pipe to $0.83 to $2.08 per linear foot (.3 m) of 27 in. (68.6 cm) diameter pipe. This degree of material savings will more than cover any additional labor costs, particularly if automated systems are incorporated into the impregnation operation. Also, the projected availability of elemental sulfur will increase significantly over the next few decades as desulfurized coal becomes a major source of energy. The impregnation of concrete sewer pipe could well benefit from such an availability.

Federal and State surveys project that over 90,000 miles of new sewage collection pipe, at a cost of approximately $17 billion will be required nationally by 1990. In developing these costs, it was assumed that conventional construction methods and materials would be used to place the sewer pipe. Obviously, even a minor improvement in these methods could result in a significant savings in the overall EPA Construction Grants Program and other construction programs and, thus, ultimately to the individual tax payer.

This report was submitted in fulfillment of Grant No. S802651 by the Southwest Research Institute under sponsorship of the U.S. Environmental Protection Agency. This report covers the period April, 1974 to April, 1979, and work was completed as of March, 1979.

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Special thanks are extended to Gifford-Hill Pipe Company and Mr. Harry T. Peck, who furnished the concrete pipe and transportation of the materials to the participating cities. They also furnished special reinforced and nonreinforced pipe for the strength improvement studies.

Owens-Corning supplied a number of fiberglass manholes, Polyfoam Industries furnished polyethylene manhole rings, and Ray-Chem supplied heat shrinkable plastic jointing materials. United States Pipe and Foundry furnished ductile iron and cement lined pipe. For all of these materials we are grateful.

We would also like to acknowledge Mr. Hugh Masters, EPA Project Officer, for his cooperation and assistance on this project.

SECTION 1

CONCLUSIONS

1. A three year time span has not been sufficient to observe measurable differences between the concrete controls and the impregnated concrete pipe. With few exceptions the final measurements are the same as the initial measurements.

2. For optimum corrosion protection, impregnation should initiate at the inside diameter and progress to the outside diameter. It has been found that due to certain concrete pipe manufacturing techniques, the inside diameter is very nearly impermeable and hence, impregnation has progressed from the outside diameter to the inside diameter. Therefore, unless saturation has occurred it is possible for impregnated pipe to have the same corrosion rate initially as the concrete control, since corrosion normally originates at the inside diameter and progresses to the outside diameter.

3. Preheating the concrete pipe to 300°F (150°C), improves the absorption rate of the sulfur. The length of time required to heat and dry the concrete pipe directly in the molten sulfur bath would be prohibitive for commercial consideration. Pipe, preheated to 300°F (150°C) had adequate sulfur absorption after two hours submersion. Impregnating the pipe under a liquid head of 10-20 ft (3-6 m) should further reduce the time of impregnation.

4. The age or curing of the concrete pipe can dramatically effect the degree of impregnation. Pipe that has been exposed to the elements for two years was found not to absorb sulfur to the same extent as new pipe and consequently, strength improvements were not as dramatic as for new pipe.

5. The strength of sulfur impregnated concrete pipe is a function of the sulfur absorbed. Generally, a 4 to 5% increase in weight yields a strength increase of 80% over that of the concrete control. For example, a 12 in. (30.5 cm) diameter nonreinforced concrete control will fail at a load of 2500 lbs/linear ft (36.5 KN/m) as opposed to approximately 4500 lbs/linear ft (65.7 KN/m) for a sulfur impregnated nonreinforced concrete pipe.

6. A "D" load of 4500 lbs/linear ft (65.7 KN/m) for the sulfur impregnated pipe is still in excess of the 3750 lbs/linear ft (54.7 KN/m) ultimate load specification for Class V 12 in. (30.5 cm) diameter pipe. (See page 20 for explanation of "D" load).

7. Considerable material savings can be realized by eliminating the reinforcing steel in concrete pipe and substituting sulfur impregnation. These savings can vary from 14 to 27 cents per linear foot (.3m) of 12 in. (30.5 cm) pipe to 83 cents to $2.08 per linear foot (.3m) of 27 in. (68.6 cm) diameter pipe. This degree of material savings will more than cover any additional labor costs, particularly if automated systems are incorporated into the production.

8. The projected availability of elemental sulfur will increase significantly over the next few decades as desulfurized coal becomes a major source of energy. The impregnation of concrete sewer pipe could well benefit from such an availability.

SECTION 2

RECOMMENDATIONS

1. The unanimous recommendation of all parties involved in the subject program has been to continue to monitor the sites until some failure occurs. In most of the domestic lines, exposure of the aggregate is beginning to occur and certainly over the next five years, some dramatic changes should begin to be observed. Accelerated field testing, by proper pH adjustment of the sewage in a controlled section of line, could shorten this waiting period.

2. When dramatic changes begin to occur, or when failure of the pipe is detected, samples of the pipe materials should be retrieved and analyzed.

3. Special studies should be initiated to determine the improvements possible with 18 to 27 in. (45.7 to 68.6 cm) diameter by sulfur impregnation. This effort would require the close cooperation of industry since special joints of reinforced and nonreinforced pipe would have to be supplied for the impregnation studies.

4. Any additional studies should also investigate a change in the cement aggregate ratios and aggregate gradations for optimum strength/cost relationships.

5. A study should be made on the optimum time/strength relationships of steam cured pipe.

6. Once these relationships are established, a semi-commercial endeavor, with a comprehensive cost analysis should be undertaken to produce some of this intermediate size pipe and install it for performance evaluations.

SECTION 3

INTRODUCTION

The corrosion of sewer lines poses a double threat. In badly corroded lines the sewage or wastes can exfiltrate, contaminating groundwater. Infiltration can also occur where there is a high water table or in cases of severe rainstorms, thus causing a burden on the sewers and treatment plants. While more corrosion resistant types of sewer pipe are on the market (i.e., PVC, reinforced plastic mortar, etc.) they are generally more expensive than concrete pipe and they are currently limited in size.

The work discussed in this report is a follow-on to a laboratory study completed earlier by Southwest Research Institute (SwRI) under U.S. Environmental Protection Agency (EPA) Contract No. 14-12-835. During this study, covered in an EPA report entitled, "Impregnation of Concrete Pipe" 11024 EQE 06/71, several promising materials were developed in the laboratory for impregnating concrete pipe. Further testing indicated corrosion resistance was improved ten fold or greater at an economically attractive cost. It was realized that field testing would be required to verify this improvement under service conditions and further laboratory studies would help characterize and optimize the impregnation concepts.

During the latter part of the above-mentioned laboratory study, a number of samples of 6 in. (15.2 cm) diameter pipe coated or impregnated with various material were placed in the vapor space of a diversion box in Harlingen, Texas. After a two year exposure period, the specimens were retrieved.

The concrete control was badly corroded, losing from 0.125 to 0.25 in. (0.3 to 0.6 cm) of material from its surface. A modified sulfur formulation, by contrast, was completely intact and showed no signs of corrosive attack. The hydrofluoric acid treated sample was erratic in its performance, having some areas where no attack had occurred and other areas where some corrosion had taken place. Overall, it was in much better condition than the concrete control. One sample impregnated with elemental sulfur was as badly corroded as the concrete control. It had been anticipated that the bacteria might use the elemental sulfur in the pipe as a source of food and this indeed appears to have been the case.

A comparison of corrosion between the concrete control, the sulfur impregnated, and the modified sulfur impregnated specimens are shown in Figure 1. For the most part, the rest of the samples were no better than the control with the exception of one vinyl chloride-acrylic copolymer coating which had remained intact. The principal function of the coatings was envisioned as linings for manholes or other structures rather than as linings for concrete sewer pipe.

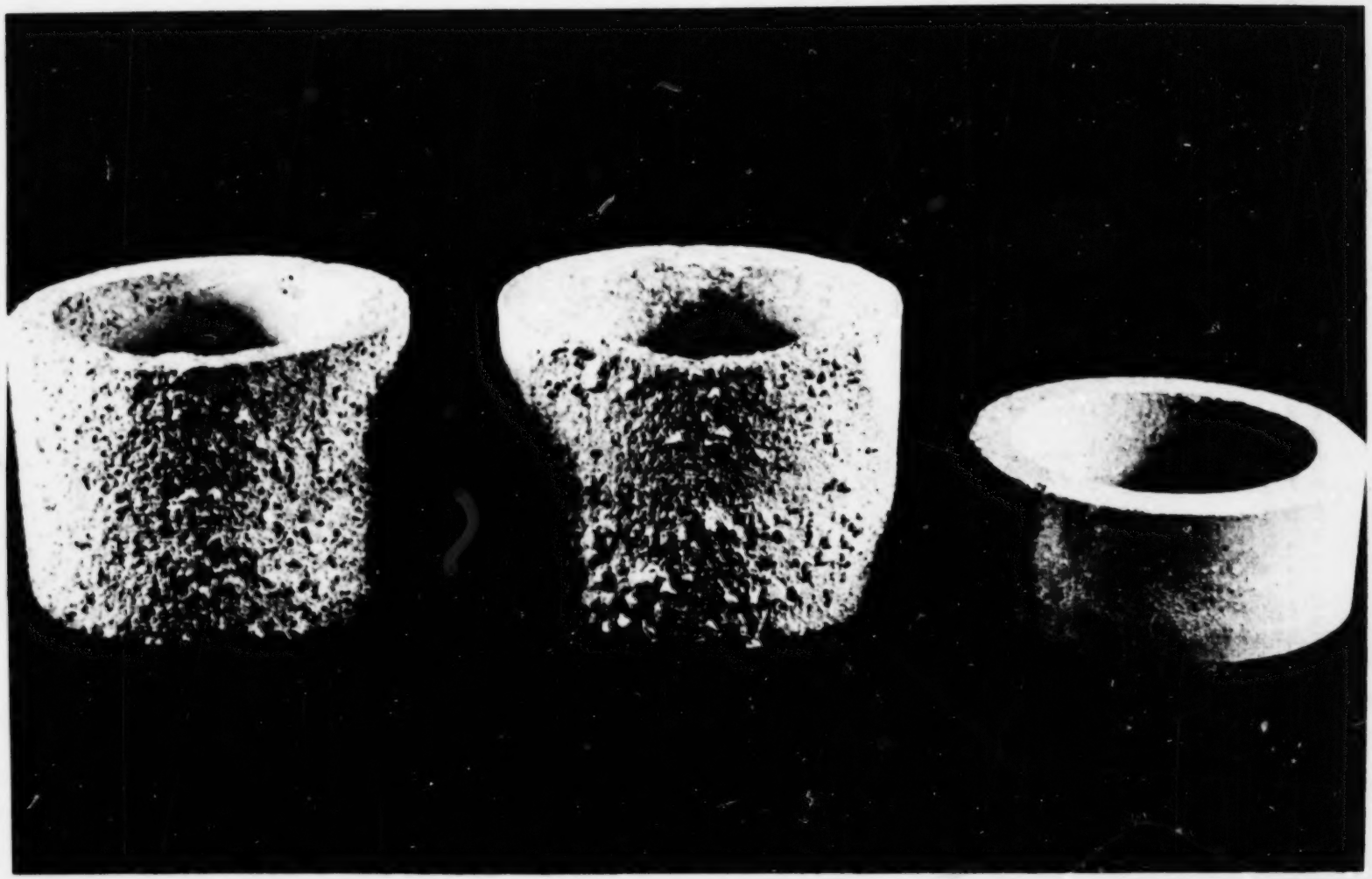

Figure 1. Concrete, Sulfur Impregnated, and Sulfur/Bactericide Impregnated rings exposed for 2 years in the vapor space in a sewer

A grant to cover field testing was originally awarded to the Texas Water Quality Board, but in July of 1976 was transferred to SwRI. The results of this study are presented in this report.

SECTION 4

IMPREGNATION PROCESSES

The pipe was impregnated by simply submerging it into either the sulfur formulation or the acid solution. The length of time required to obtain adequate protection is dependent on many variables. With the sulfur formulations, the moisture content of the pipe has a direct effect on the time of impregnation since all of the moisture must be raised to temperature and boiled off since the sulfur vats are normally held at 300°F (150°C). There is a significant color difference between moist pipe and dry pipe that has been observed, due to the moisture reacting with the sulfur to form sulfides with the iron and other constituents in the concrete. Further study will be required to determine whether any significant performance difference exists. The wall thickness and mass of the pipe also affect the time of impregnation. The pipe temperature also has a great influence on the time and degree of penetration.

Until vats large enough to accommodate full joints of pipe were fabricated and operational, it was not known that a joint of concrete pipe could be impregnated in molten sulfur without fracturing or suffering some damage.

Once the vats were operational, experiments using 6 in. (15.2 cm) and 10 in. (25.4 cm) diameter nonreinforced and 12 in. (30.5 cm) diameter reinforced concrete pipe were conducted. No problems were encountered and it was found that substantial strength improvement had been accomplished.

Because of the 5 year time limit of the grant, it was desirable to place the impregnated pipe under test as early as possible. This would then give the longest possible evaluation period.

Since it was important to prepare the pipe in the quickest manner, an arbitrary decision was made to work a split shift and impregnate the pipe for 12 hrs. Facilities were not available to predry the pipe before impregnation, therefore, all pipe were taken directly from the yard, irregardless of the weather, and submerged in the molten sulfur bath or HF vat for 12 hrs or 24 hrs depending on the wall thickness.

Since there was little or no gas generation from the pipe after 12 hrs, it was assumed that near saturation of the pipe had been accomplished. Studies conducted later in the program, indicate this may have been correct for the 6 in. (15.2 cm) and 10 in. (25.4 cm) diameter pipe with wall thickness of approximately 1 in. (2.5 cm). However, depending upon moisture content in the thicker walled 12 in. (30.5 cm) pipe, less than saturation was accomplished even after 24 hrs. A more detailed discussion on this aspect occurs on page

12. In all cases the liquid head of molten sulfur varied between 12 (30.5) and 24 in. (61 cm) maximum. This process took approximately two months to accomplish and was completed during February, 1975. Pipe shipments to the various test sites occurred between April, 1975 and August, 1975.

Figure 2 shows the sulfur impregnation facility while Figure 3 shows some of the impregnated pipe awaiting shipment. The white pipe has been treated with HF while the dark pipe is sulfur impregnated.

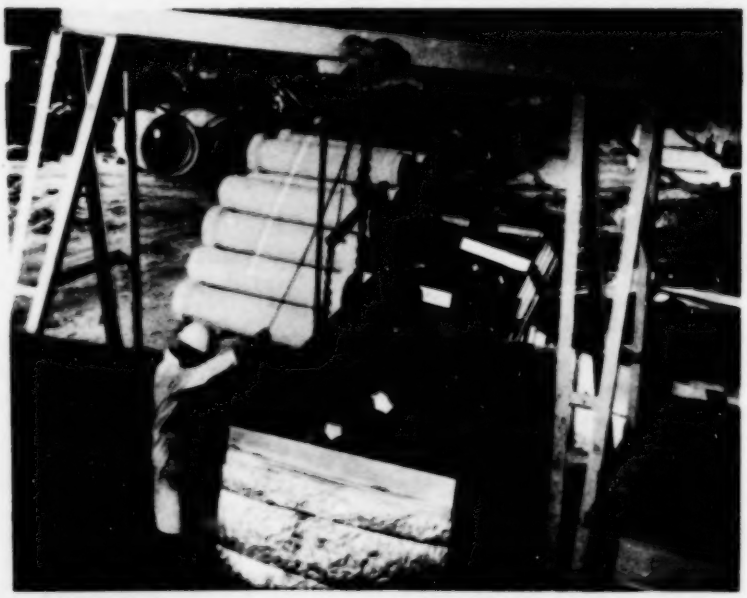

Figure 2. Pipe being extracted from the Sulfur Impregnation Vat

Figure 3. Some of the impregnated pipe awaiting shipment

SECTION 5

INSTALLATION AND SAMPLING

Installation of the experimental sewer lines began in April, 1975, in Dallas. The first site was the 12 in. (30.5 cm) line on Macatee Drive. This site included clay, ductile iron, modified sulfur impregnated, hydrofluoric acid treated, and reinforced concrete control. A rubber "0" ring gasket was used on all the concrete and impregnated concrete joints.

In addition this site includes two epoxy lined concrete manholes, a fiberglass manhole, a latex coated manhole, and a plastic manhole cover ring.

The second site in Dallas was constructed during April and May, 1975, on Showbend Street. This line used the 10 in. (25.4 cm) diameter, nonreinforced concrete controls, modified sulfur impregnated, hydrofluoric acid treated, polyvinyl chloride, ductile iron, and a double treated pipe - hydrofluoric acid treated followed by modified sulfur impregnation. This line had one epoxy lined manhole, two latex coated manholes, one plastic manhole cover ring, and a shrink-fit gasket jointing the PVC pipe to the ductile iron.

In July, 1975, Beaumont installed 200 ft (61 m) of nonreinforced concrete control, hydrofluoric acid treated, and modified sulfur impregnated, 10 in. (25.4 cm) diameter pipe on Bob Street. This site included an epoxy lined manhole, a fiberglass manhole, and a latex coated manhole. The impregnated pipe was tied into a new line of truss pipe that was being installed at the same time.

During September and October, 1975, approximately 100 ft (30.5 m) of modified sulfur impregnated, hydrofluoric acid treated, and nonreinforced concrete control 6 in (15.2 cm) diameter pipe was installed in Pecos. This line is to ultimately service five houses that will be built by the Pecos High School crafts class. The first house was completed in May, 1976. No additional houses have been built, but since principal concern is with corrosion caused to the exterior of the concrete pipe due to high sulfate concentrations in the soil, the location is adequate.

The corrosion of concrete in the Pecos area can be extremely severe. The perimeter curbing around the parking lot at one motel has been corroded approximately 1/2 in. (1.3 cm) in five years. Depending on the depth of the water table, some areas are worse than others. On the initial visit to Pecos, a concrete meter box which was fabricated by city crews, was returned to the Institute and impregnated with the modified sulfur formulation. In June, 1975, the meter box was returned to Pecos for installation.

The final site in Harlingen was installed during December, 1975, and January, 1976. Modified sulfur impregnated, hydrofluoric acid treated, double treated-hydrofluoric acid treated followed by modified sulfur impregnated, and reinforced concrete control were installed. One hundred feet (30.5 m) of 12 in. (30.5 cm) diameter reinforced line were placed. One manhole was epoxy lined, one manhole was fiberglass, and one manhole was coated with latex. In addition, one plastic manhole cover ring was installed.

The total costs of installation, materials and transportation were increased considerably over original estimates. In Table 1 the incurred costs are compared with the anticipated costs that had been submitted with the grant proposal.

TABLE 1. ANTICIPATED/INCURRED COSTS

Participants	Anticipated	Incurred
Southwest Research Institute	$ 3,200.00	$ 7,575.30
City of Dallas	17,990.00	39,858.86
City of Beaumont	2,350.00	4,246.55
City of Harlingen	600.00	2,466.05
City of Pecos	500.00	800.00
Gifford-Hill Pipe Co.	5,400.00	16,846.01
United States Pipe & Foundry (ductile iron and cement lined pipe)	-	2,299.32
Owens-Corning (Fiberglass Manholes)	-	950.00
Polyfoam, Inc. (Polyethylene Manhole Rings)	-	250.00
Ray-Chem (Heat shrinkable plastic jointing materials)	-	100.00

An initial visit was made to each site as soon after construction as was practical, to sample the flow and measure the inside diameters of each type of pipe. Sampling was accomplished using N-Con Sentry 500 automatic samplers and flow measurement was done (except in Dallas where they used their own device) with a Manning Dipper level recorder. The detailed analyses for each of the sites is included in Appendix A.

The inside diameters were also measured for each type of pipe at each site. These measurements were taken with calipers on the vertical diameter of each end of exposed pipe in the manhole as shown in Figure 4. By far the most extensive sampling and analyses was conducted by the City of Dallas. A

seven day scheduling program was established and samples were gathered and then analysed for BOD, TSS, pH, sulfates, nitrates, sulfides, etc. TV inspections were made of each line prior to implementing the sampling schedule and the internal diameter measurements of the various types of pipe in the test lines. The detailed data are listed in Appendix A.

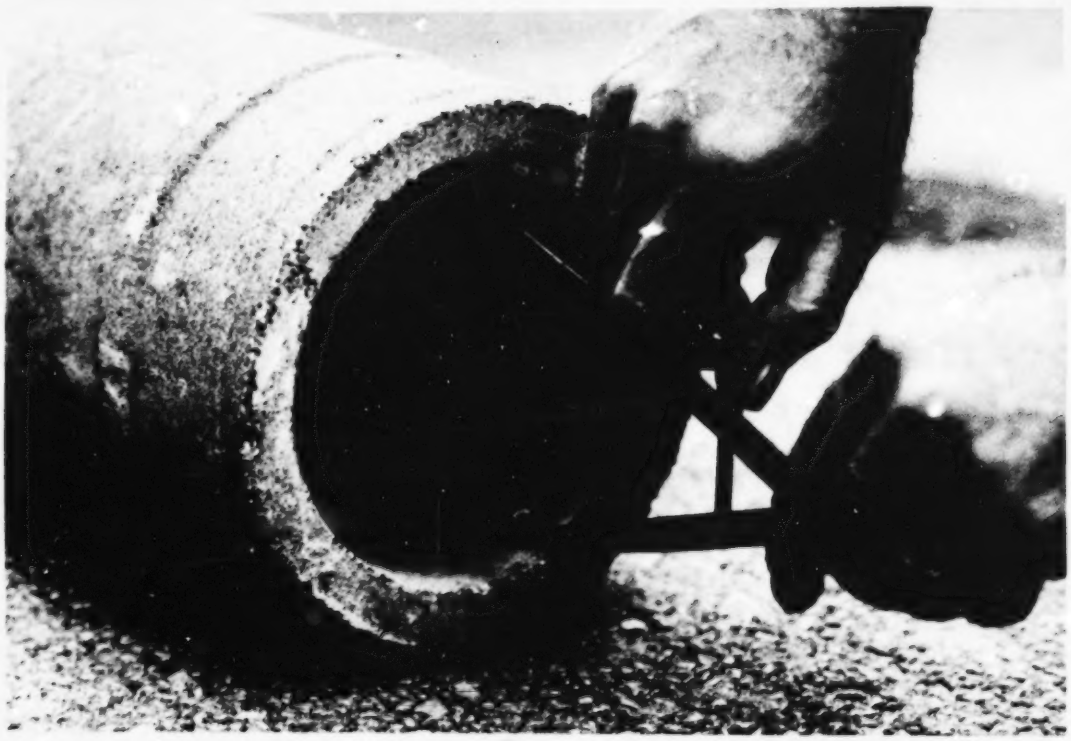

Figure 4. Measuring inside diameter with calipers

SECTION 6

RESULTS TO DATE

The impregnated pipe has been in service approximately three years. To date the corrosion against the concrete control has not been as severe as originally anticipated and as a result, the data is inconclusive.

Tables 2 to 5 list the inside pipe diameter for the different pipe in each location. The data is not well defined since some impregnated pipe appears to be corroding the same as the concrete control while others are decidely better. The reason for this did not become apparent until after the optimization studies commenced. From the observations of the laboratory specimens cut from pipe in the original laboratory study, the impregnation of the sulfur has proceeded from the outside to the inside fairly uniformly. Once the strength studies were underway on the subject program and specimens were broken, observation of the impregnation of the pipe joints revealed an interesting fact. The pipe was being impregnated from the outside diameter, towards the inside diameter since the inside diameter is mechanically worked and nearly impervious. This is good for everything, except impregnation! For corrosion resistance against sewerage, the protection of the inside diameter is the most important factor. Thus, what appears to have happened is that unless saturation occured, the corrosion rate for impregnated pipe will be the same as for concrete, until the impregnated surface is exposed. Thus, until significant loss occurs or until complete failure of the control can be ascertained, definite conclusions will be difficult to make.

Another difficulty encountered was the build-up of sediment at the bottom of the manholes and in lines making measurements very difficult to take. For the final inspection, a request was made to have the lines flushed and the manholes cleaned as was the practice in Dallas which always made the inspection much easier.

Final inspections were made in March, 1979. The only line showing significant damage was the industrial line in Dallas on Macatee Drive. Considerable difficulty was encountered in cleaning the sewer and only after persistent effort could the TV camera cable be fished through a section of the line. Upon TV inspection, it became apparent why there had been such a problem. The bottom half of the line was badly eroded, so much so, that the reinforcing wire was exposed and had prevented the high pressure nozzle of the cleaning hose and the TV cable from progressing smoothly through the sewer. All concrete sections at this location, both impregnated and control were in the same deteriorated condition. The inspection showed the crown of the pipe to be in excellent condition indicating that excessively corrosive liquids had flowed through the line causing bottom deterioration. Sulfuric acid is

TABLE 2. INDUSTRIAL LINE-KENDALL DRIVE/MACATEE-DALLAS SITE

Type	Pipe Diameter - inches (cm) July '75	July '76	June '78	March '79	Corrosion
Clay	11.9 (30.1)	11.9 (30.1)	11.9 (30.1)	11.9 (30.1)	0 (0)
Ductile Iron	12.2 (31.0)	12.2 (31.0)	12.2 (31.1)	Bottom Out	Total Failure
Sulfur-1	12.1 (30.7)	12.2 (31.0)	12.6 (32.1)	13.2 (33.6)	1.1 (2.9)
Sulfur-2	12.0 (30.6)	12.0 (30.6)	12.2 (31.2)	12.4 (31.4)	0.4 (0.8)
HF	11.9 (30.3)	12.1 (30.7)	12.2 (30.9)	12.3 (31.2)	0.4 (0.9)
Concrete Control (reinforced)	11.9 (30.3)	12.1 (30.8)	12.4 (31.5)	12.6 (31.9)	0.8 (1.6)

TABLE 3. DOMESTIC LINE-SHOWBEND-DALLAS SITE

Type	Pipe Diameter - inches (cm) July '75	July '76	June '78	March '79	Corrosion
PVC	9.7 (24.7)	9.6 (24.4)	9.6 (24.4)	9.6 (24.4)	- (-)
Ductile Iron	10.4 (26.4)	10.4 (26.4)	10.4 (26.3)	10.2 (26.2)	- (-)
Sulfur-2	10.0 (25.5)	10.0 (25.5)	10.3 (26.1)	10.3 (26.2)	0.3 (0.7)
Sulfur-2	10.1 (25.6)	10.0 (25.5)	10.3 (26.2)	10.4 (26.3)	0.3 (0.7)
HF	10.0 (25.3)	10.1 (25.7)	10.0 (25.5)	10.2 (25.9)	0.2 (0.6)
HF	10.0 (25.5)	10.1 (25.6)	10.1 (25.6)	10.1 (25.7)	0.1 (0.2)
HF/S	10.0 (25.5)	10.1 (25.6)	10.0 (25.3)	10.2 (25.8)	0.2 (0.3)
Concrete Control (nonreinforced)	10.0 (25.3)	10.2 (25.9)	10.4 (26.5)	10.4 (26.3)	0.4 (1.0)

TABLE 4. DOMESTIC LINE-BOB ST.-BEAUMONT

	Pipe Diameter - inches (cm)				
Type	July '75	July '76	June '78	March '79	Corrosion
Sulfur-2	9.9 (25.20)	9.9 (25.20)	10.3 (26.10)	10.0 (25.3)	0.04 (0.1)
Sulfur	10.0 (25.40)	10.0 (25.50)	10.2 (25.80)	10.0 (25.5)	0.04 (0.1)
HF	9.9 (25.20)	10.0 (25.30)	10.2 (25.90)	10.0 (25.3)	0.04 (0.1)
Concrete Control (nonreinforced)	10.0 (25.45)	10.0 (25.50)	10.2 (25.80)	10.0 (25.4)	0 (0)

TABLE 5. DOMESTIC LINE-HARLINGEN

	Pipe Diameter - inches (cm)				
Type	Feb. '75	Aug. '76	Feb. '78	March '79	Corrosion
Sulfur-1	11.2 (28.4)	11.3 (28.6)	11.2 (28.4)	11.1 (28.2)	- (-)
Sulfur-2	11.9 (30.0)	11.9 (30.3)	12.0 (30.5)	12.1 (30.7)	0.2 (0.7)
HF/S	11.4 (28.9)	11.4 (29.0)	11.4 (29.0)	11.5 (29.2)	0.1 (0.3)
HF	11.6 (29.5)	11.6 (29.4)	11.5 (29.3)	11.6 (29.4)	- (-)
Concrete Control (reinforced)	11.6 (29.5)	11.6 (29.5)	11.7 (29.6)	11.5 (29.2)	- (-)

suspected since a battery plant is upstream. Further inspection of the ductile iron pipe indicated that the bottom was completely gone in some areas. The City of Dallas has bypassed this portion of the line and will be digging up the line so that sections can be returned to the laboratory for inspection.

SECTION 7

IMPREGNATION FOR STRENGTH IMPROVEMENT

During the summer of 1978, the strength studies were initiated using some 8 in. (20.3 cm) diameter pipe that was on hand. This pipe had been obtained two years earlier and had been exposed in the yard for the entire duration.

In addition, as the result of another program, two improved impregnation vats were available. One was used as a dryer to preheat the pipe and the second was used for impregnation.

Initial work employed the 8 in. (20.3 cm) diameter nonreinforced pipe. The pipe was placed in the dryer and dried to a constant weight. The maximum weight loss was approximately 2% for all the joints tested. This pipe was then placed in the molten sulfur bath and weight gain as a function of time was determined and is shown in Figure 5.

These values were approximately half of what was expected. In the previous laboratory study*, water absorption of 4 to 5% was achieved and sulfur absorptions of 7 to 8% due to liquid sulfur's specific gravity of 1.8 were obtained. Attempts to increase the water absorption of this two year old pipe using air pressure above a liquid head yielded only 2-3% weight increase with water. Continued hydration of the cement has long been known as one of the most effective means of increasing the watertightness of concrete. It was not appreciated that such dramatic changes could occur within a two-year period.

Selected joints of the impregnated pipe were tested and the results are plotted in Figure 6. It was appreciated that the age of the pipe was an important factor for strength improvement. For example, it had been determined that air dried pipe had to be 20-28 days old before dramatic strength improvements would be seen by impregnation. Thus, the optimum time to impregnate concrete is as soon as desired strengths are obtained and before further hydration causes sealing.

The three edge bearing test as defined by ASTM C497, Standard Methods of Testing Concrete Pipe or Tile, consists of supporting the pipe barrel on two parallel longitudinal strips and applying the load throughout a top bearing beam also extending the full length of the barrel. The test load is expressed

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*Ludwig, A.C., and J.M. Dale. Impregnation of Concrete Pipe. EPA 11024EQE 06/71. 73 pp.

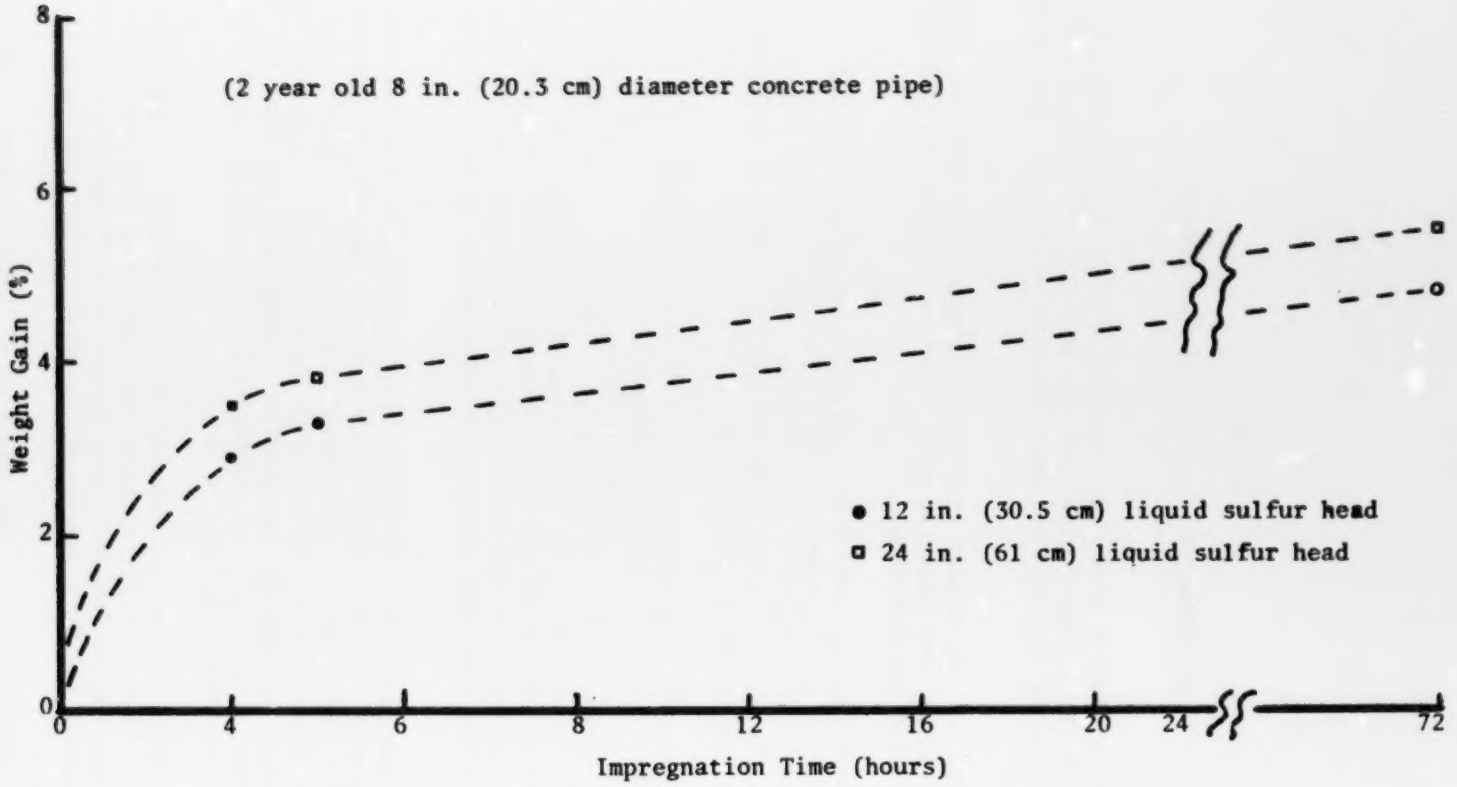

Figure 5. Pipe Weight Gain as a function of time for Sulfur impregnated pipe

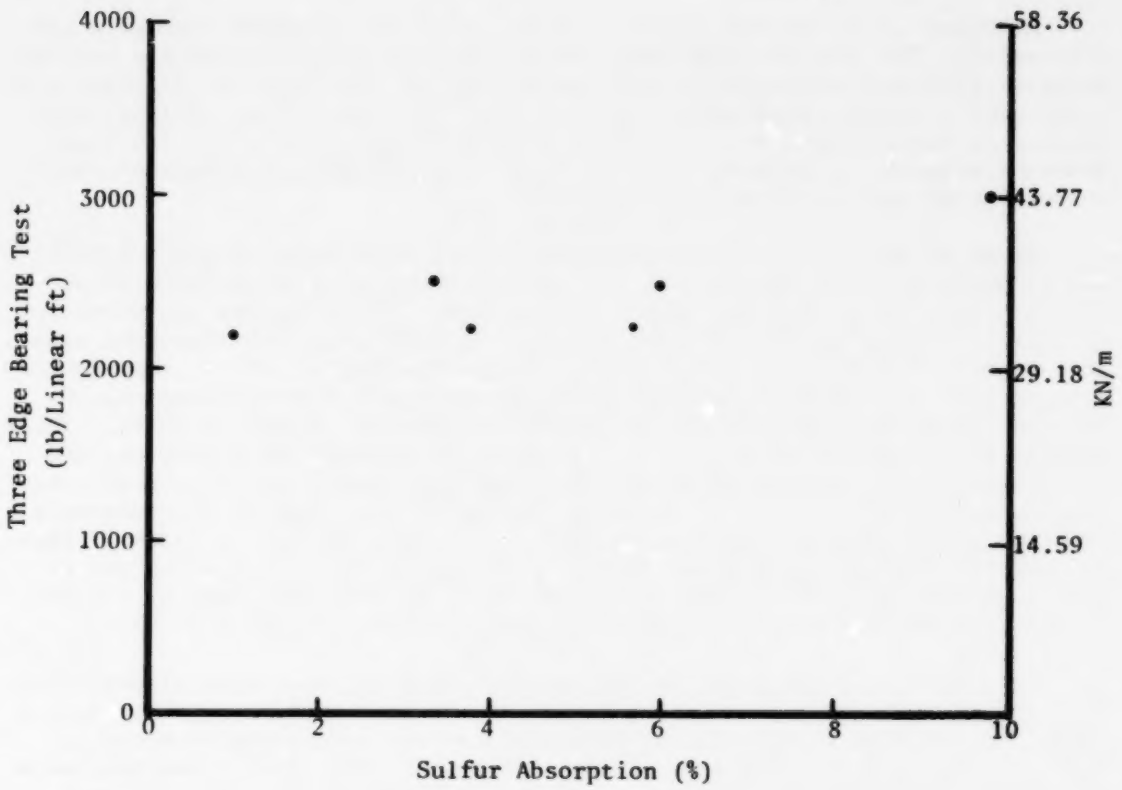

Figure 6. Three edge bearing test as function of sulfur absorption for 2 year old 8 in. (20.3 cm) diameter pipe

in pounds-force per linear foot of pipe (newtons per linear meter).

ASTM Standard C 76 for reinforced concrete culvert, storm drain and sewer pipe specifies strength classes based on "D" load at 0.01 in. (0.0254 cm) crack. The 0.01 in. (0.0254 cm) crack "D" load is the three-edge bearing test load in pounds per linear foot for foot of inside diameter (newtons per linear meter per millimeter of inside diameter) which produces a crack 0.01 in. (0.0254 cm) wide for a length of 12 in. (30.5 cm).

Attempts to obtain new joints of 8 in. (20.3 cm) diameter pipe were unsuccessful. The concrete pipe industry has dropped production of the smaller diameter pipe and consequently none was available. The smallest diameter concrete pipe currently available is 12 in. (30.5 cm) reinforced. A local concrete pipe manufacturer volunteered to specially make some 12 in. (30.5 cm) diameter without reinforcing wire and ultimately supplied 12 joints of this nonreinforced and 12 joints of reinforced.

These 12 in. (30.5 cm) nonreinforced joints were dried at 300°F (150°C) for 24 hours and then impregnated for various times in a molten bath of sulfur with only 1 ft (30.5 cm) liquid sulfur head. These results are presented in Table 6. The results were also compared against other nonreinforced pipe that were tested early in the program. When comparing all of the impregnated pipe against the standard strength and extra strength nonreinforced pipe of the same diameters, there is a substantial improvement in the strength. These results are presented in Figure 7. In Figure 8, impregnated reinforced and nonreinforced pipe are compared against different classes of reinforced pipe. The load required to initiate the 0.01 in. (0.025 cm) crack is approximately twice as great with the impregnated pipe as for the controls or Class IV pipe and considerably above that for Class V pipe. With the 12 in. (30.5 cm) diameter pipe these loads varied from 3750 (54.7) to 5000 lb/linear ft (73 KN/m) with the average being approximately 4500 lb/linear ft (65.7 KN/m).

In contrast to the good quality concrete used in pipe, some efforts were directed to impregnating a very poor quality concrete product used for garden curbs and stepping stones. These products are very porous and as shown in Figure 9, the sulfur absorption was in the area of 20%. With these specimens the Modulus of Rupture was increased from approximately 200 psi (1.38 MPa) to between 500 (3.45) and 1000 psi (6.89 MPa). The difficulty encountered with these specimens was that the concrete was too porous. Although the sulfur flowed very readily into the blocks, it flowed away just as readily when the specimens were removed from the bath.

Because of the improved strength imparted by impregnation, two alternatives for reducing costs without sacrificing performance may be possible. Impregnated nonreinforced pipe, particularly in the 12-36 in. (30.5-91.4 cm) diameter pipe range, could prove to be a replacement for steel reinforced pipe. A second consideration is to reduce the wall thickness and/or quantity of cement by reducing the cement/aggregate ratio and thereby reduce costs and yet retain the minimum strengths by impregnation.

The next section considers the economics of such a tradeoff.

TABLE 6. RESULTS OF 12 IN. (30.5 CM) DIAMETER IMPREGNATED CONCRETE PIPE

Condition	Length of Impregnation	Total Load lb/linear ft.	Total Load (KN/m)	% Sulfur Absorption
Control-nonreinforced	-	2500	36.5	-
Control-reinforced	-	1875	27.4	-
Control-reinforced	-	2625	38.3	-
Impregnated-nonreinforced	2 hr	4625	67.5	5.0
" "	2 hr	4375	63.8	3.7
" "	4 hr	4310	62.9	4.5
" "	4 hr	3750	54.7	3.9
" -reinforced	8 hr	4560	66.5	4.6
" "	8 hr	4560	66.5	3.7
Impregnated-nonreinforced	3 days	4500	65.7	5.7
" -reinforced	4 days	5000	73.0	5.8
" -nonreinforced	4 days	4375	63.8	6.0

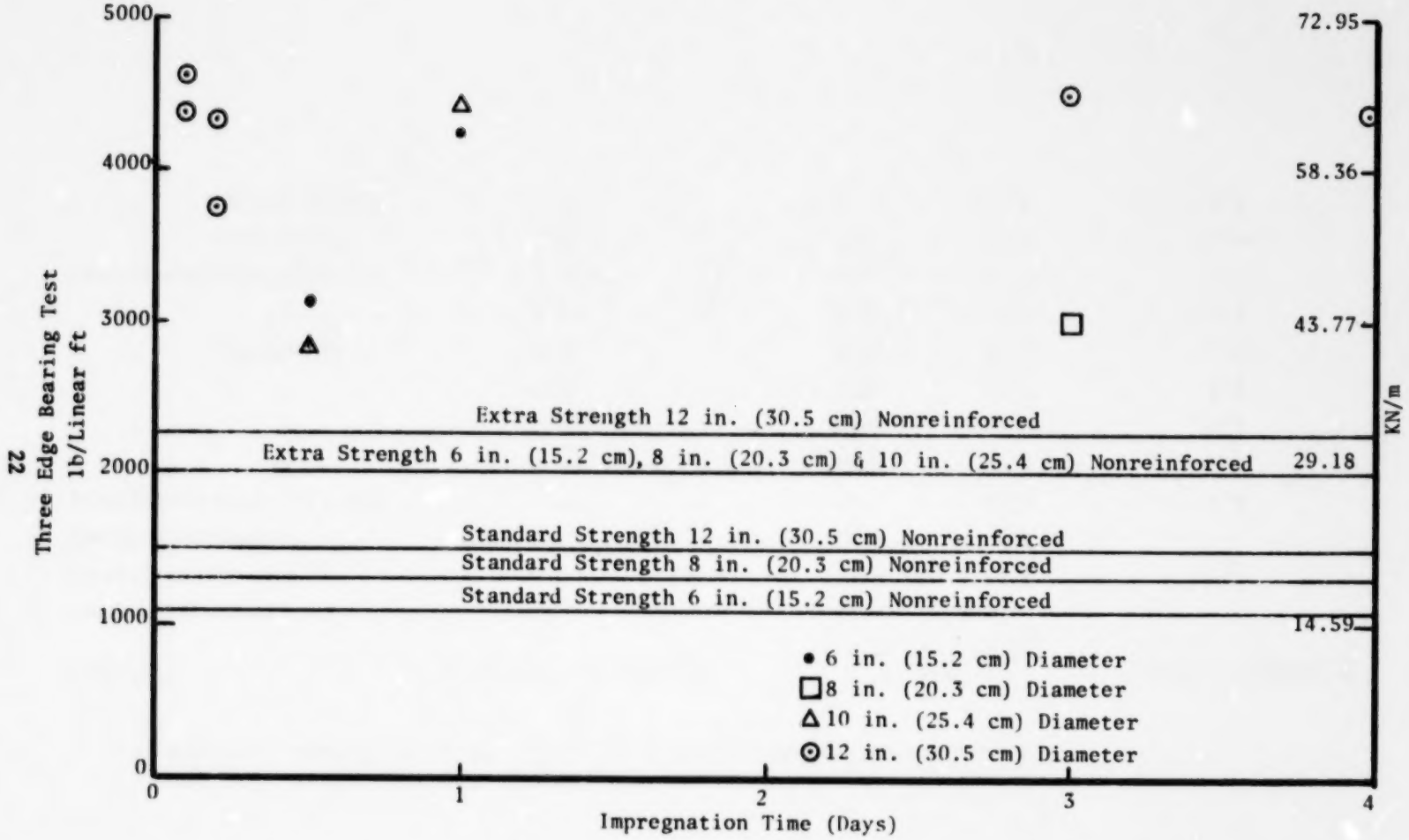

Figure 7. Three edge bearing tests as a function of impregnation time compared to specification standards for nonreinforced pipe

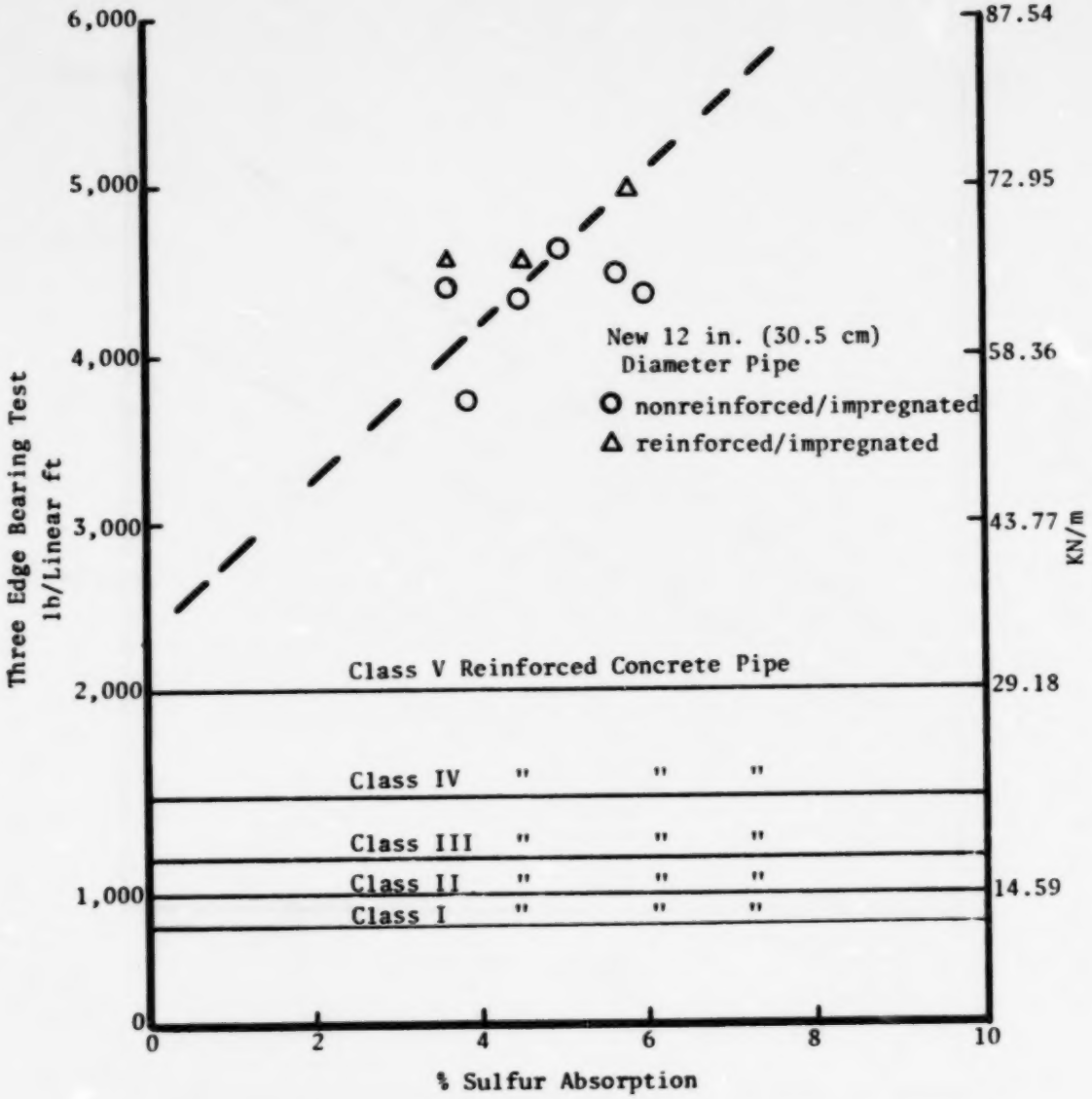

Figure 8. Three edge bearing test as a function of sulfur absorption compared to reinforced pipe specifications

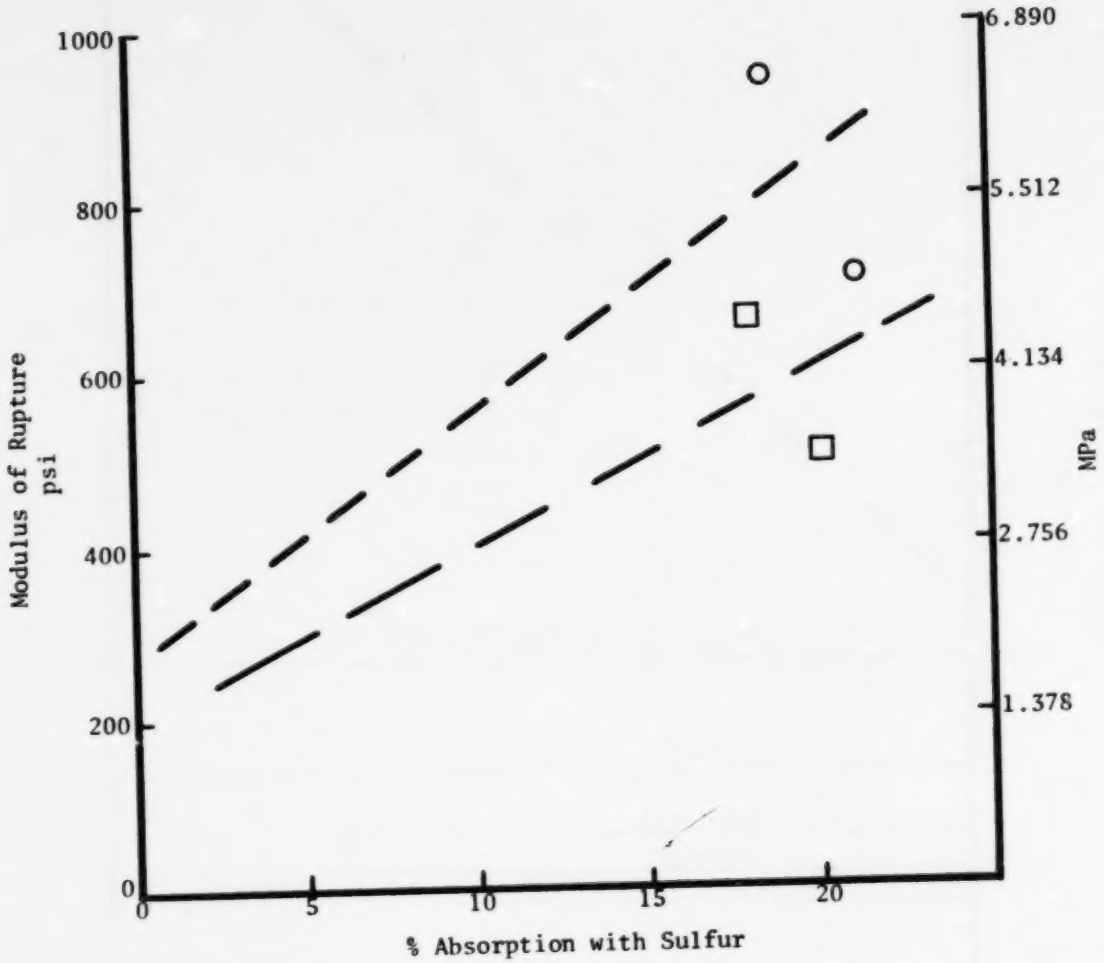

Figure 9. Modulus of rupture for porous concrete specimens as a function of sulfur absorption

SECTION 8

ECONOMIC TRADEOFFS

The dramatic strength improvement provided by sulfur impregnation leads to the possibility that impregnation of concrete pipe could provide more than adequate strength at lower pipe costs.

This could be achieved in a number of ways, from reducing material costs to reducing weight and ultimately reducing transportation costs, to allowing longer lengths and hence lower installation costs. The principal costs to be addressed will consider reducing material costs and reduced weights to reduce transportation costs.

To discuss in great detail the economics of concrete pipe would require proprietary information which was neither sought nor desired. For purposes of this discussion, however, general figures would suffice as long as there is a considerable difference in cost between impregnation and the other systems of reinforcement or strength improvement. These data are presented for 12 in. (30.5 cm) and 27 in. (68.6 cm) diameter pipe which are at this time, thought to be the extremes of the most promising sizes to immediately benefit from sulfur impregnation. Certainly greater economic benefit would be realized in the larger diameter pipe, perhaps to 48 in. (122 cm) diameter and this should ultimately be pursued.

In the first consideration the reinforcing steel would simply be eliminated and the standard wall thickness would remain the same. The pipe would be impregnated to give strength improvements comparable to those presented earlier in Figures 7 and 8. This then becomes an economic tradeoff between the cost of steel and the cost of sulfur. A comparison of these material costs is presented in Tables 7 and 8.

The data in Tables 7 and 8 are presented for both Class III and Class V pipe for each of the two diameters considered. The materials savings for the 12 in. (30.5 cm) diameter pipe range from 14 to 27 cents per linear foot (30.5 cm) of pipe or put another way, from 56 cents to $1.08 per 4 ft (1.22 m) joint of pipe. The savings for the larger diameter pipe are greater, ranging from 83 cents to $2.08 per linear foot (30.5 cm) or $6.64 to $16.64 per 8 ft (2.6 m) joint. These greater savings in the larger diameter pipe are due to the fact that the quantity and hence cost of reinforcing steel rises dramatically as the pipe diameter increases.

An alternative to sulfur impregnation for strength improvement would be to increase the wall thickness. To obtain strengths comparable to those from

TABLE 7. MATERIALS SAVINGS USING SULFUR IMPREGNATION VS. REINFORCING STEEL OR EXTRA WALL THICKNESS

Pipe Diameter	Class	Wall Thickness	Wt. of Reinforcing Steel lb/linear ft.	Cost of Reinforcing @ 25¢/lb $/linear ft.	Cost of Sulfur $/linear ft.	Materials Savings $/linear ft.	Cost of Concrete to Double Wall $/linear ft.	Materials Savings $/linear ft.
12 in.	III	2 in.	1.2	.30	.16	.14	.88	.72
12 in.	V	2 in.	1.7	.43	.16	.27		
27 in.	III	3-1/4 in.	5.1	1.30	.47	.83	2.88	2.41
27 in.	V	3-1/4 in.	10.2	2.55	.47	2.08		

TABLE 8. MATERIALS SAVINGS USING SULFUR IMPREGNATION VS. REINFORCING STEEL OR EXTRA WALL THICKNESS

Pipe Diameter	Class	Wall Thickness	Wt. of Reinforcing Steel kg/linear m	Cost of Reinforcing @ 25¢/kg $/linear m	Cost of Sulfur $/linear m	Materials Savings $/linear m	Cost of Concrete to Double Wall $/linear m	Materials Savings $/linear m
30.5 cm	III	5.1 cm	1.8	.98	.52	.46	2.89	2.37
30.5 cm	V	5.1 cm	2.5	1.41	.52	.89		
68.6 cm	III	8.3 cm	7.6	4.27	1.54	2.73	9.45	7.91
68.6 cm	V	8.3 cm	15.2	8.37	1.54	6.83		

impregnation would require doubling the wall thickness. These costs are also included in Table 7 and it can be seen that the savings using sulfur impregnation are even more favorable than in eliminating the reinforcing steel. The concrete costs used for this comparison were $30 per cubic yard (.76 m^3) for a 1:3 mix.

A second consideration would be to retain the reinforcing steel and reduce the wall thickness by half. When impregnated, the pipe would still meet strength specification. This assumes, of course, that a concrete pipe with half the normal wall thickness would still have enough green strength to be handled. The material savings on concrete would then amount to approximately $1.37 less 27¢ for sulfur impregnation, giving a net materials savings of $1.10 per 4 ft (1.2m) joint of 12 in. (30.5 m) pipe. Concrete savings of $9.50 less $1.90 for sulfur impregnation would give a net savings of $7.60 per 8 ft (2.4 m) joint of 27 in. (8.2 cm) pipe. In addition, this pipe would weigh approximately half that of the conventional pipe and as a result, freight costs would be cut in half.

Pipe is shipped and freight is paid on a weight basis. In other words if the pipe weight could be cut in half without sacrificing quality or strength, twice as many pipe could be shipped by the same truck, reducing freight costs to 1/2.

Other potential areas of savings using sulfur impregnated pipe would be in cement costs if leaner concrete mixes could be used. Another potential area of savings would be in reduced labor costs if the strength improvement from impregnation were great enough to allow joints of twice the conventional length to be manufactured.

The really significant advantage of using sulfur, however, is in the fact that sulfur will be readily available in contrast to ever increasing shortages of steel and cement, not to mention escalating prices. The Department of Energy estimates that the sulfur available in 1985 from coal gasification/liquefaction will be 84 million tons/year (7.6×10^6 Kg/year) and an annual consumption in this country of 12 million tons (1.1×10^{10} Kg). By the year 2000 there should be 156 million tons (1.4×10^{11} Kg) available annually. Thus in a world where supplies are constantly shrinking, sulfur offers the potential of growing availability.

In addition, EPA has estimated that over 90,000 miles of new sewage collection pipe, at a cost of approximately $17 billion, would be required nationally by 1990. In developing these costs, it was assumed that conventional materials and construction methods would be used to manufacture the sewer pipe. Obviously, even a minor improvement in these methods could result in a significant savings in the overall Construction Grants program and, thus, ultimately to the individual tax payer.

APPENDIX A

ANALYSES FOR INDIVIDUAL SITES

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	7.2	2.8	7.5	7.0	7.1	7.2	7.4	7.2	7.2	7.2	6.7	7.8
Chlorides (mg/L)	62	47	54	48	41	37	46	55	43	46	55	58
Sulfides (mg/L) No Preservative	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	70	1,010	95	88	88	78	85	74	78	70	500	75
Total Suspended Solids (mg/L)	98	62	64	20	8	8	8	44	32	68	156	114
Dissolved Oxygen (mg/L)	4.7	6.5	3.7	5.4	7.0	7.0	7.0	2.3	4.0	3.2	5.7	5.7
BOD_5 (mg/L) Composite	66											

Sample Date: 5-7-75 (1:10 p.m.) to
5-8-75 (12:10 p.m.)

12 in. (30.5 cm) line in Macatee Drive, east from railroad tracks to Bengal Drive

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	7.8	7.7	7.8	7.8	7.5	7.5	7.5	11.7	115	9.8	9.6	8.2
Chlorides (mg/L)	57	56	61	48	39	38	36	72	66	41	56	61
Sulfides (mg/L) No Preservative	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	57	81	75	57	73	76	77	105	112	120	61	53
Total Suspended Solids (mg/L)	112	80	72	54	42	20	12	286	192	80	180	84
Dissolved Oxygen (mg/L)	4.1	4.6	3.0	2.7	49	6.8	7.0	7.7	8.0	8.9	5.0	4.8
BOD_5 (mg/L) Composite	110											

Sample Date: 5-8-75 (12:00 p.m.) to 5-9-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	7.0	7.0	7.1	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Chlorides (mg/L)	145	78	66	72	57	42	86	42	42	39	42	42
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	67	68	71	75	82	85	83	81	83	85	83	77
Total Suspended Solids (mg/L)	180	132	114	152	180	104	48	62	52	52	64	94
Dissolved Oxygen (mg/L)	7.1	7.3	7.4	6.9	6.8	7.0	6.6	6.7	6.7	6.4	6.3	6.0
BOD_5 (mg/L) Composite	310											

Sample Date: 5-9-75 (11:00 a.m.) to 5-10-75 (10:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.8	7.0	7.0	7.0	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Chlorides (mg/L)	64	94	76	43	45	40	37	39	39	40	37	40
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	68	70	75	82	82	80	82	82	75	82	85	75
Total Suspended Solids (mg/L)	102	90	92	64	52	36	32	24	24	22	24	28
Dissolved Oxygen (mg/L)	4.7	6.2	7.1	6.4	6.7	7.1	6.7	6.4	6.5	6.4	6.2	5.4
BOD_5 (mg/L) Composite	250											

Sample Date: 5-10-75 (12:00 noon) to 5-11-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.8	6.9	7.0	7.0	7.0	7.0	7.0	8.6	7.4	7.3	7.1	7.2
Chlorides (mg/L)	38	28	29	30	34	33	37	55	61	59	50	51
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	-	-	-	-	-	-	-	-	-	-	-	-
Total Suspended Solids (mg/L)	32	56	66	56	66	60	50	198	338	328	360	330
Dissolved Oxygen (mg/L)	6.6	5.0	5.6	6.7	7.0	6.9	6.7	6.7	7.7	7.5	6.7	6.3
BOD_5 (mg/L) Composite	400											

Sample Date: 5-11-75 (12:00 noon) to 5-12-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.7	6.6	6.7	6.8	6.9	6.9	7.2	10.3	9.8	7.5	7.3	7.2
Chlorides (mg/L)	62	51	54	54	48	43	41	68	67	51	52	62
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	68	62	68	65	71	78	80	less than 45	76	84	84	84
Total Suspended Solids (mg/L)	416	162	172	154	100	66	64	584	496	382	246	178
Dissolved Oxygen (mg/L)	5.0	6.9	6.9	6.9	7.1	6.8	6.7	6.4	6.8	6.8	6.8	6.3
BOD_5 (mg/L) Composite	300											

Sample Date: 5-12-75 (12:00 noon) to 5-13-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	7.2	7.2	7.2	7.2	7.2							
Chlorides (mg/L)	87	88	81	70	62							
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.0							
Sulfates (mg/L)	73	72	1000	1000	1000							
Total Suspended Solids (mg/L)	160	156	114	90	76							
Dissolved Oxygen (mg/L)	7.4	7.0	6.8	2.2	5.5							
BOD_5 (mg/L) Composite	280											

Sample Date: 5-13-75 (12:00 noon) to 5-15-75 (4:00 p.m.)
End of Analysis on First Test Section

APPENDIX A

ANALYSES FOR INDIVIDUAL SITES (CONT'D.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.8	6.8	6.8	6.9	6.8	6.8	6.9	6.9	6.9	6.9	6.9	7.0
Chlorides (mg/L)	44	46	45	63	51	40	42	35	37	35	46	40
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	83	93	90	87	104	104	97	94	90	90	97	94
Total Suspended Solids (mg/L)	414	466	290	306	376	354	174	106	74	106	230	182
Dissolved Oxygen (mg/L)	7.8	7.5	8.3	7.8	7.0	7.4	7.1	7.5	7.7	7.3	6.5	6.1
BOD_5 (mg/L) Composite	240											

Sample Date: 5-15-75 (12:00 noon) to 5-16-75 (11:00 a.m.)

10 in. (25.4 cm) line near Showbend Drive and Symphony Lane, behind the Jim Miller Pump Station

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	7.4	7.5	7.6	7.5	7.5	7.5	7.5	7.4	7.4	7.4	7.5	7.4
Chlorides (mg/L)	43	45	45	46	52	49	45	45	43	42	43	46
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates (mg/L)	96	90	97	98	91	100	101	96	95	86	86	103
Total Suspended Solids (mg/L)	770	362	248	316	198	310	296	138	104	70	198	512
Dissolved Oxygen (mg/L)	7.7	7.2	7.5	4.9	6.8	7.2	7.4	8.1	8.3	7.9	7.2	6.5
BOD_5 (mg/L) Composite	340											

Sample Date: 5-16-75 (12:00 noon) to 5-17-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	7.2	7.3	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Chlorides (mg/L)	52	53	63	59	52	62	66	48	42	45	39	47
Sulfides (mg/L)	0.2	0.5	0.8	0.3	0.6	0.7	0.8	0.7	0.9	0.9	1.6	2.0
Sulfates (mg/L)	109	96	87	97	95	96	94	88	90	75	90	84
Total Suspended Solids (mg/L)	368	602	444	212	168	130	116	132	86	60	272	440
Dissolved Oxygen (mg/L)	2.0	3.5	4.4	5.8	6.0	6.5	6.8	6.6	6.9	6.6	5.8	5.0
BOD_5 (mg/L) Composite	340											

Sample Date: 5-17-75 (12:00 noon) to 5-18-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.8	6.9	6.8	6.9	6.9	6.9	6.9	6.9	6.9	7.0	7.0	7.0
Chlorides (mg/L)	43	55	38	51	49	46	44	42	40	44	45	44
Sulfides (mg/L)	2.0	1.5	2.0	1.9	2.4	2.2	5.2	3.0	3.1	2.3	3.0	1.8
Sulfates (mg/L)	63	80	75	98	88	85	85	80	66	77	75	75
Total Suspended Solids (mg/L)	264	242	206	220	176	250	790	148	176	160	216	228
Dissolved Oxygen (mg/L)	2.8	2.6	4.3	5.3	5.2	6.1	7.3	7.3	7.3	6.2	5.8	4.8
BOD_5 (mg/L) Composite	330											

Sample Date: 5-18-75 (12:00 noon) to 5-19-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.8	7.0	7.1	7.1	7.2	7.1	7.2	7.2	7.1	7.1	7.2	7.2
Chlorides (mg/L)	50	36	34	35	50	48	42	48	44	36	48	36
Sulfides (mg/L)	2.3	2.6	2.6	3.0	3.8	3.6	0.6	0.5	0.9	2.7	3.2	3.5
Sulfates (mg/L)	90	82	75	70	72	85	96	87	88	87	92	97
Total Suspended Solids (mg/L)	350	60	52	48	98	262	378	344	220	160	104	138
Dissolved Oxygen (mg/L)	6.1	6.1	6.2	5.9	5.6	5.3	6.2	6.2	5.6	5.3	5.3	5.6
BOD_5 (mg/L) Composite	250											

Sample Date: 5-20-75 (12:00 noon) to 5-21-75 (11:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.8	7.4	7.5									
Chlorides (mg/L)	36	43	41									
Sulfides (mg/L)	0.0	0.0	0.0									
Sulfates (mg/L)	89	82	82									
Total Suspended Solids (mg/L)	764	752	1102									
Dissolved Oxygen (mg/L)	4.9	0.8	0.8									
BOD_5 (mg/L) Composite	200											

Sample Date: 5-21-75 (12:00 midnight) to 5-22-75 (7:00 a.m.)

Analysis	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12
pH	6.9	7.0	7.0	7.0	7.1	7.1	7.1	7.0	7.0	7.1	7.1	7.1
Chlorides (mg/L)	36	25	36	36	40	45	37	35	50	51	44	42
Sulfides (mg/L)	0.0	0.0	0.0	0.0	0.5	1.8	0.0	0.0	0.2	0.4	0.3	0.2
Sulfates (mg/L)	81	87	82	83	95	101	101	97	94	98	106	106
Total Suspended Solids (mg/L)	96	94	46	118	154	318	206	2688	442	508	230	152
Dissolved Oxygen (mg/L)	6.5	6.6	7.0	6.0	4.4	2.9	7.1	7.0	7.0	7.1	7.1	7.1
BOD_5 (mg/L) Composite	310											

Sample Date: 5-22-75 (12:00 noon) to 5-23-75 (11:00 a.m.)

APPENDIX A

ANALYSES FOR INDIVIDUAL SITES (CONT'D.)

Analysis	Sample No. 1	2	3	4
pH	7.4	7.5		
Chlorides (mg/L)	80	115		
Sulfides (mg/L)	0.1	0.2		
Sulfates (mg/L)	597	367		
Total Suspended Solids (mg/L)	530	484		
Dissolved Oxygen (mg/L)	N.D.	N.D.		
BOD_5 (mg/L) Composite		220		
Fluoride (mg/L)	0.8	0.8		

Sample Date: 1-23-78 (2:30 p.m.) to (8:00 p.m.) Kendall Dr.-Dallas, Tx.

Analysis	Sample No. 1	2	3	4
pH	7.3	7.5		
Chlorides (mg/L)	90	210		
Sulfides (mg/L)	0.0	0.0		
Sulfates (mg/L)	281	336		
Total Suspended Solids (mg/L)	320	304		
Dissolved Oxygen (mg/L)	10.4	9.9		
BOD_5 (mg/L) Composite		240		
Fluoride (mg/L)	1.3	1.2		

Sample Date: 1-24-78 (9:00 a.m.) to (2:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	10.5	6.3	9.3	10.4
Chlorides (mg/L)	100	95	80	65
Sulfides (mg/L)	0.0	0.0	0.1	0.1
Sulfates (mg/L)	330	337	702	515
Total Suspended Solids (mg/L)	594	142	940	908
Dissolved Oxygen (mg/L)	9.1	9.9	10.4	10.1
BOD_5 (mg/L) Composite				140
Fluoride (mg/L)	1.1	1.0	1.0	1.0

Sample Date: 1-25-78 (4:00 a.m.) - (10:30 a.m.) - (4:00 p.m.) - (11:30 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.4	7.5	7.1	7.3
Chlorides (mg/L)	100	100	100	100
Sulfides (mg/L)	0.1	0.2	0.2	0.3
Sulfates (mg/L)	590	331	528	125
Total Suspended Solids (mg/L)	270	312	256	80
Dissolved Oxygen (mg/L)	10.8	10.6	11.4	10.9
BOD_5 (mg/L) Composite				230
Fluoride (mg/L)	0.7	0.8	0.7	0.8

Sample Date: 1-26-78 (10:00 a.m.) - (1:00 p.m.) - (2:30 p.m.) - (8:30 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.1	7.3	7.6	7.5
Chlorides (mg/L)	95	90	100	95
Sulfides (mg/L)	0.0	0.1	0.1	0.0
Sulfates (mg/L)	99	401	772	451
Total Suspended Solids (mg/L)	86	440	720	310
Dissolved Oxygen (mg/L)	10.8	10.6	10.2	10.2
BOD_5 (mg/L) Composite				150
Fluoride (mg/L)	0.8	0.9	0.9	0.8

Sample Date: 1-27-78 (2:30 a.m.) - (8:30 a.m.) - (2:30 p.m.) - (8:30 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.3	7.7	8.0	
Chlorides (mg/L)	90	85	110	
Sulfides (mg/L)	0.0	0.0	0.0	
Sulfates (mg/L)	313	212	105	
Total Suspended Solids (mg/L)	100	292	60	
Dissolved Oxygen (mg/L)	10.6	11.6	11.6	
BOD_5 (mg/L) Composite			130	
Fluoride (mg/L)	1.0	0.9	0.8	

Sample Date: 1-28-78 (1:00 p.m.) - (2:30 p.m.) - (8:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.4	7.5	7.5	7.5
Chlorides (mg/L)	60	60	60	60
Sulfides (mg/L)	N.D.	0.0	0.0	0.0
Sulfates (mg/L)	103	98	91	87
Total Suspended Solids (mg/L)	166	84	424	52
Dissolved Oxygen (mg/L)	10.2	10.6	10.6	10.6
BOD_5 (mg/L) Composite				160
Fluoride (mg/L)	1.0	0.8	0.8	0.7

Sample Date: 1-29-78 (2:30 a.m.) - (8:30 a.m.) - (2:30 p.m.) - (8:30 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.1	5.7		
Chlorides (mg/L)	60	65		
Sulfides (mg/L)	0.0	N.D.		
Sulfates (mg/L)	311	837		
Total Suspended Solids (mg/L)	92	326		
Dissolved Oxygen (mg/L)	10.4	10.2		
BOD_5 (mg/L) Composite		180		
Fluoride (mg/L)	0.8	0.8		

Sample Date: 1-30-78 (2:30 a.m.) - (8:30 a.m.)

Analysis	Sample No. 1	2	3	4
pH	7.2	7.4	7.4	
Chlorides (mg/L)	115	120	125	
Sulfides (mg/L)	0.0	0.0	0.0	
Sulfates (mg/L)	160	148	150	
Total Suspended Solids (mg/L)	1152	452	860	
Dissolved Oxygen (mg/L)	9.2	9.4	8.9	
BOD_5 (mg/L) Composite			270	
Fluoride (mg/L)	1.1	1.1	1.2	

Sample Date: 2-6-78 (8:00 a.m.) - (2:00 p.m.) - (8:00 p.m.)

APPENDIX A

ANALYSES FOR INDIVIDUAL SITES (CONT'D.)

Analysis	Sample No. 1	2	3	4
pH	7.3	6.9		
Chlorides (mg/L)	130	130		
Sulfides (mg/L)	0.1	0.1		
Sulfates (mg/L)	297	285		
Total Suspended Solids (mg/L)	23	81		
Dissolved Oxygen (mg/L)	6.3	4.6		
BOD_5 (mg/L) Composite		90		
Fluoride (mg/L)	N.D.	N.D.		

Sample Date: 3-10-78 (9:30 a.m.) - (3:00 p.m.) Showbend Lane-Dallas, Tx.

Analysis	Sample No. 1	2	3	4
pH	7.3	7.3	7.2	7.5
Chlorides (mg/L)	125	110	130	120
Sulfides (mg/L)	0.1	0.0	0.1	0.1
Sulfates (mg/L)	136	156	137	96
Total Suspended Solids (mg/L)	315	285	267	370
Dissolved Oxygen (mg/L)	6.4	6.4	6.0	5.0
BOD_5 (mg/L) Composite				60
Fluoride (mg/L)	0.7	0.6	0.6	0.5

Sample Date: 3-11-78 (9:00 a.m.) - (12:00 noon) - (2:00 p.m.) - (8:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.4	7.4	7.4	7.3
Chlorides (mg/L)	75	95	95	95
Sulfides (mg/L)	0.1	0.5	0.7	N.D.
Sulfates (mg/L)	99	124	132	131
Total Suspended Solids (mg/L)	114	424	360	776
Dissolved Oxygen (mg/L)	7.8	7.0	5.9	6.8
BOD_5 (mg/L) Composite				110
Fluoride (mg/L)	1.2	1.0	0.9	0.8

Sample Date: 3-12-78 (2:00 a.m.) - (8:00 a.m.) - (2:00 p.m.) - (8:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.0	7.2	7.3	7.4
Chlorides (mg/L)	90	105	100	105
Sulfides (mg/L)	N.D.	0.3	0.7	1.0
Sulfates (mg/L)	128	151	145	126
Total Suspended Solids (mg/L)	196	344	214	294
Dissolved Oxygen (mg/L)	9.1	6.5	5.0	5.6
BOD_5 (mg/L) Composite				70
Fluoride (mg/L)	0.9	0.8	1.0	0.7

Sample Date: 3-13-78 (2:00 a.m.) - (8:00 a.m.) - (2:00 p.m.) - (8:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.1	7.2	7.3	7.0
Chlorides (mg/L)	90	105	100	108
Sulfides (mg/L)	0.5	1.1	1.3	1.7
Sulfates (mg/L)	110	156	130	138
Total Suspended Solids (mg/L)	168	482	298	1152
Dissolved Oxygen (mg/L)	7.9	5.8	7.3	2.3
BOD_5 (mg/L) Composite				140
Fluoride (mg/L)	0.6	0.7	0.8	0.6

Sample Date: 3-14-78 (2:00 a.m.) - (8:00 a.m.) - (2:00 p.m.) - (8:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.0	7.1	7.2	7.2
Chlorides (mg/L)	90	108	105	112
Sulfides (mg/L)	1.0	N.D.	2.4	N.D.
Sulfates (mg/L)	131	146	156	167
Total Suspended Solids (mg/L)	282	1932	1656	1654
Dissolved Oxygen (mg/L)	8.6	7.8	4.8	5.3
BOD_5 (mg/L) Composite				250
Fluoride (mg/L)	0.4	0.5	0.3	0.3

Sample Date: 3-15-78 (2:00 a.m.) - (8:00 a.m.) - (2:00 p.m.) - (8:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.2	7.3		
Chlorides (mg/L)	105	100		
Sulfides (mg/L)	2.5	N.D.		
Sulfates (mg/L)	139	130		
Total Suspended Solids (mg/L)	1512	834		
Dissolved Oxygen (mg/L)	5.4	6.9		
BOD_5 (mg/L) Composite		270		
Fluoride (mg/L)	0.5	0.6		

Sample Date: 3-16-78 (8:00 a.m.) - (2:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.5			
Chlorides (mg/L)	90			
Sulfides (mg/L)	N.D.			
Sulfates (mg/L)	123			
Total Suspended Solids (mg/L)	204			
Dissolved Oxygen (mg/L)	8.5			
BOD_5 (mg/L) Composite	170			
Fluoride (mg/L)	0.4			

Sample Date: 3-17-78 (2:00 a.m.)

APPENDIX A

ANALYSES FOR INDIVIDUAL SITES (CONT'D.)

Analysis	Sample No. 1	2	3	4
pH	7.6	7.4	7.1	7.5
Chlorides (mg/L)	180.8	216.2	177.3	180.8
Sulfides (mg/L)	0.65	0.50	0.20	0.35
Sulfates (mg/1)	91.2	100.8	76.8	81.6
Total Suspended Solids (mg/L)	184	240	343	227
Dissolved Oxygen (mg/L)	0.0	0.0	0.0	0.0
BOD_5 (mg/L) Composite	173.3	170.0	156.7	86.7

Sample Date: 2-26-76 (10:00 a.m.) - (2:00 p.m.) - (6:00 p.m.) - (11:00 p.m.)
12 in. (30.5 cm) line Harlingen, Tx.)

Analysis	Sample No. 1	2	3	4
pH	7.2	7.1		
Chlorides (mg/L)	198.6	198.6		
Sulfides (mg/L)	0.4	0.2		
Sulfates (mg/L)	100.8	96.0		
Total Suspended Solids (mg/L)	109	94		
Dissolved Oxygen (mg/L)	1.9	2.6		
BOD_5 (mg/L) Composite	127	107		

Sample Date: 3-20-79 (10:00 a.m.) - (2:00 p.m.)

Analysis	Sample No. 1	2	3	4
pH	7.1	7.1		
Chlorides (mg/L)	191.5	184.4		
Sulfides (mg/L)	0.0	0.7		
Sulfates (mg/L)	100.8	91.2		
Total Suspended Solids (mg/L)	105	65		
Dissolved Oxygen (mg/L)	0.8	1.4		
BOD_5 (mg/L) Composite	120	86.7		

Sample Date: 3-21-79 (6:00 p.m.) - (10:00 p.m.)

APPENDIX A

ANALYSES FOR INDIVIDUAL SITES (CONT'D.)

Analysis	Sample No. 1	2	3	4
pH	8.35			
Chlorides (mg/L)	1.76			
Sulfates (mg/L)	1.06			
Carbonate	0.0			
Bicarbonate	0.01			
Calcium	0.22			

Sample Date: 6-23-76 Pecos, Tx.

GLOSSARY

1. Bactericide	sodium pentachlorophenate
2. "D" Load	Test load divided by the pipe diameter expressed in pounds-force per linear foot of diameter (newtons per linear meter per millimeter of diameter).
3. Impregnation	Absorption of sulfur by concrete products.
4. Modified Sulfur	Sulfur, containing 1-5% dicyclopentadiene or bactericide
5. Three Edge Bearing Test	ASTM C497, Standard Methods of Testing Concrete Pipe or Tile, consists of supporting the pipe barrel on two parallel longitudinal strips and applying the load throughout a top bearing beam also extending the full length of the barrel.